Changes in carbon content of a Norfolk loamy sand after 14 years of conservation or conventional tillage

P.G. Hunt, D.L. Karlen, T.A. Matheny, and V.L. Quisenberry

*ABSTRACT: Soil carbon (C) management is vital for sandy southeastern Coastal Plain (SCP) soils that are naturally low in C. A long-term investigation began in 1979 to determine if conservation tillage would increase the C content of a Norfolk loamy sand (*Typic Kandiudult*) with a cropping system that included corn (*Zea mays *L.), cotton (*Gossypium hirsutum *L.), soybean [*Glycine max *(L.) Merr.], and wheat (*Triticum aestivum *L.). Plots were 60 m (196.8 ft) long and 23 m (75.5 ft) wide with five replications. Before modern conservation tillage technology was available, increasing soil C was believed to be nearly impossible under row crop production, particularly if cotton and soybean were part of the rotation. Tillage (conventional vs. conservation) was the main plot treatment. At the beginning of the experiment, C contents were not significantly different. In years 9 to 14, the mean C content of the 0- to 5-cm (0- to 2-in) depth for conservation tillage was nearly double that for conventional tillage: 12.0 vs 7.2 g kg^{-1} (1.2 and 0.72%) ($P \leq 0.05$). The r^2 of C content vs time over the 14 years was 0.44 for the 0- to 5-cm layer of the conservation tillage plots. The slope was 0.61 g kg^{-1} yr^{-1} (0.06%), and the probability that the slope was zero was < 0.001. A smaller slope increase of 0.17 g kg^{-1} yr^{-1} (0.017%) also existed for conservation tillage at the 5- to 10-cm (2.0- to 3.9-in) depth. The C content was not consistently different between tillage treatments below the 15-cm (5.9-in) depth. Improved equipment, management, and soil quality allowed conservation tillage plots to produce greater yields during years 9 to 14. Long-term conservation tillage of row crops appears to be a viable method of increasing the C content of sandy SCP soils even when soybean and cotton are part of the rotation.*

Soil carbon (C) influences soil characteristics such as water infiltration rate, erodibility, water holding capacity, nutrient cycling, and pesticide adsorptive characteristics (Bruce et al. 1990; Follett 1987; Hudson 1994; Langdale et al. 1990; Staley et al. 1988; Stevenson 1972; West et al. 1991). Soils are also sinks for the C in atmospheric CO_2 (Kern and Johnson 1991; Schlesinger 1993). Soils of the southeastern United States, particularly sandy Coastal Plain soils, are typically low in C; values in the surface horizon are often below 10 g kg^{-1} (1.0%) (Hunt et al. 1982). Consequently, small changes in the C content are significant to the environmental and agricultural potential of these soils.

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Crop residues are important to the accumulation or loss of soil C even in the high organic matter soils of the midwestern United States (Barber 1979; Larson et al. 1972; Larson et al. 1978). In sandy southeastern Coastal Plain soils, crop residues constitute a significant portion of the C content. Annual additions of > 7 Mg ha^{-1} (3.1 t/ac) of crop residues are common for corn, soybean, or wheat when water is not limiting; cotton, on the other hand, is a lower residue producer (Hunt and Matheny 1993; Hunt et al. 1987; Karlen and Gooden 1990; Karlen et al. 1984; Karlen et al. 1987). In pasture, residue additions from legumes and grasses can greatly increase soil C (Blue 1979). Unfortunately, addition of row crop residues to conventionally tilled (plowed or disked) soils does not increase soil C content (Beale et al. 1955). In fact, crop residue alone will not maintain C levels obtained in no-till once the soil has been placed into cultivation with conventional tillage (Bruce et al. 1995).

Conservation tillage has been reported to increase both the C content of the soil surface horizon and crop yield (Bruce et al. 1990; Unger 1991). However, long-term studies of conservation tillage versus conventional tillage in the southeastern Coastal Plain, particularly with cotton, have not been reported. We investigated accumulation of C in a Norfolk loamy sand during 14 years of conservation and conventional tillage with cropping systems that included corn, cotton, soybean, and wheat.

Materials and methods

We initiated a long-term study in 1979 to assess the impact of conservation tillage and residue management on a soil typical of the southeastern Coastal Plain. The study was conducted on a 2.65-ha (6.5-ac) plot of Norfolk loamy sand (fine-loamy, siliceous, thermic *Typic Kandiudult*) at the Pee Dee Research and Education Center near Florence, South Carolina. The coordinates are latitude 34° 18′, longitude 79° 44′, and the elevation is 37 m (121.4 ft) above mean sea level. Treatments were arrayed in a randomized complete block design with split plots and five replications. Plots were 30 m (98.4 ft) long and 23 m (75.5 ft) wide. Initially, conventional tillage and conservation tillage with crop residue removal of 0%, 66%, and 90% were the four main treatments, and irrigation was the split-plot treatment. The first three years of the experiment are described in Karlen et al. (1984). Conventional tillage consisted of multiple diskings to incorporate crop residues, fertilizers, and lime as well as cultivation to control weeds. Conservation tillage eliminated surface tillage, but both tillage treatments received in-row subsoiling at planting to fracture a root restrictive layer (E horizon) that reforms

Interpretive Summary

Soil carbon (C) content is important for agricultural production, water quality, and atmospheric carbon dioxide balance. One potential method of increasing soil C is reduced surface tillage (conservation tillage). A long-term experiment was started in 1979 to determine changes in soil C content of a typical sandy soil on which corn, cotton, soybean, and wheat were grown under conservation and traditional tillage. The C content changed slowly; but after 14 years of conservation tillage, the C content of the surface six inches of soil had nearly doubled while the C content of traditionally tilled soil had not increased.

Key words: conservation tillage, soil organic carbon, long-term experiments, southeastern Coastal Plains, crop residues

annually within these soils (Busscher et al. 1986). A Brown and Harden Super Seeder and John Deere Flex 71 planters were used through 1987. A Kelley conservation-till subsoiler and International 800 conservation tillage planters were used after 1987.

Continuous corn was grown on the site in 1979, 1980, and 1981. There were no significant differences in soil C or crop yield among the residue treatments when removal ceased in 1982. Each block was split in half to allow each crop of a two-year rotation to be grown annually. One of the conservation tillage plots was tilled to establish a conservation/conventional tillage split in each block of the rotation treatments. Thus, a split-split existed for crop rotation and tillage. The first rotation was a two-year rotation of corn-wheat-soybean in which wheat and soybean were grown in the same year. This cropping practice was continued through the corn harvest of 1986. The site remained fallow in 1987, and weeds were controlled using Round-up [Isopropylamine salt of N-(phosphonomethyl) glycine]. Water was applied using overhead irrigation guns until 1987. Irrigation had not resulted in a major interaction with tillage for crop yield, and a nonirrigated system was more economical for long-term research. Therefore, irrigation was discontinued in 1987, and the plot size doubled to 60 m (196.8 ft) long and 23 m (75.5 ft) wide. Both crops of a replicated two-year rotation of corn-wheat-cotton (wheat and cotton grown in the same year) were established in 1988, and this rotation continues to the present. Rotation replicate I started with corn in 1988, and rotation replicate II started with cotton in 1988. Fertilizer, lime, and pesticide were applied using Clemson University recommendations (Anonymous 1982).

Soil samples were collected from the Ap [0 to 5, 5 to 10, and 10 to 15-cm (0 to 2, 2 to 3.9, and 3.9 to 5.9-in) horizon in each plot from 1979 to 1983, in 1987, and from 1988 to 1992. From 1988 to 1992, samples were also taken from depths of 15 to 30, 30 to 45, 45 to 60, and 60 to 90 cm (5.9 to 11.8, 11.8 to 17.7, 17.7 to 23.6, and 23.6 to 35.4 in). Crop residues were removed from the surface before samples were taken. Soil surface samples were collected manually until 1988 and thereafter with a Giddings soil sampler. All samples were air-dried, crushed, and passed through a 2-mm (0.08-in) sieve to remove plant materials.

Table 1. Carbon content of the surface horizon of a Norfolk loamy sand during a 14-year conservation tillage study in South Carolina

Soil Depth	Tillage	Years 0	s.e.†	1-3	s.e.	9-14	s.e.
cm		g kg^{-1}					
0-5	Conventional	6.3	0.8	7.2	0.3	7.2	0.2
	Conservation	5.3	0.2	7.3	0.4	12.0	0.5
	$LSD_{0.05}$	NS		NS		*	
5-10	Conventional	5.2	1.1	7.1	0.4	5.6	0.2
	Conservation	4.6	0.3	6.2	0.4	6.3	0.3
	$LSD_{0.05}$	NS		NS		*	
10-15	Conventional	3.9	0.7	6.0	0.5	4.5	0.1
	Conservation	4.5	0.6	5.3	0.4	4.8	0.3
	$LSD_{0.05}$	NS		NS		NS	

* = Significantly different at $LSD_{0.05}$.
† = Standard error of the mean.
NS = not significantly different at $LDS_{0.05}$.

Table 2. Linear regression parameters for carbon content versus time in a Norfolk loamy sand during 14 years of conservation and conventional tillage

Tillage	Depth cm	Intercept g kg^{-1}	Slope g kg^{-1} yr^{-1}	S.E. of slope	Prob. of slope = 0	r^2
Conventional	0-5	6.3	0.13	0.05	0.01	0.08
Conservation	0-5	5.5	0.61	0.09	0.01	0.44
Conventional	5-10	6.2	0.01	0.06	0.80	0.00
Conservation	5-10	5.4	0.17	0.08	0.04	0.06
Conventional	10-15	4.9	0.03	0.06	0.61	0.01
Conservation	10-15	4.9	0.05	0.08	0.51	0.01

Samples collected in 1979 were analyzed for C using the dry combustion method (Nelson and Sommers 1982). Samples collected in 1980 through 1987 were analyzed for C using a Leco carbon analyzer. Samples collected after 1988 were analyzed for C with a Carlo-Erba carbon analyzer. Data were analyzed by analysis of variançe (ANOVA), linear regression, and least significant difference (LSD) using Statistical Analysis Systems (SAS 1985).

Results and discussion

Carbon accumulation over time. The C contents of the surface layers (0 to 5, 5 to 10, and 10 to 15 cm) ranged from 3.9 to 6.3 g kg^{-1} (0.39 to 0.63%) before the experiment was initiated (Table 1). These values, although much lower than C values of soils in some sections of the United States, are typical for a Norfolk loamy sand and similar soils under conventional tillage in the southeastern Coastal Plain of the United States (Hunt et al. 1982). This

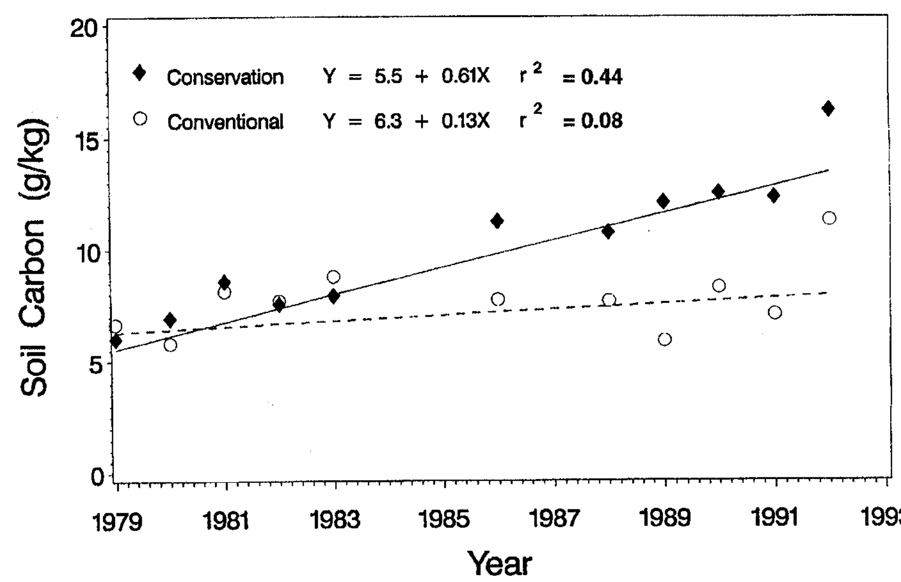

Figure 1. Regression of carbon content versus time for the 0- to 5-cm depth of a Norfolk loamy sand that received conservation or conventional tillage for 14 years

Table 3. Mean of soil organic carbon content of a Norfolk loamy sand with varying tillage during a corn-wheat-cotton rotation

Soil Depth	Tillage	Crop[†] Corn	Wheat	Cotton
cm			g kg^{-1}	
0-5	Conventional	6.6	7.6	7.5
	Conservation	11.3	12.6	12.9
	$LSD_{0.05}$	*	*	*
5-10	Conventional	5.3	6.2	5.8
	Conservation	6.2	6.4	5.9
	$LSD_{0.05}$	NS	NS	NS
10-15	Conventional	4.4	4.8	4.5
	Conservation	4.6	4.7	4.8
	$LSD_{0.05}$	NS	NS	NS
15-30	Conventional	3.7	3.9	3.6
	Conservation	3.5	4.0	3.8
	$LSD_{0.05}$	NS	NS	NS
30-45	Conventional	2.6	2.7	2.4
	Conservation	2.9	3.1	2.9
	$LSD_{0.05}$	NS	NS	NS
45-60	Conventional	2.3	2.2	2.2
	Conservation	2.7	2.1	2.2
	$LSD_{0.05}$	NS	NS	NS
60-90	Conventional	1.8	1.8	1.6
	Conservation	2.0	1.6	1.6
	$LSD_{0.05}$	NS	NS	NS

* Significantly different at $LSD_{0.05}$.
[†] Each value is a mean of 4 sampling dates from 2 rotation replicates and 2 cycles through the rotation from 1988 to 1992.
NS = not significantly different at $LSD_{0.05}$.

Table 4. Mean crop yield for two cycles of a two-year rotation of corn and double-cropped wheat and cotton grown on Norfolk loamy sand

Tillage*	Crop[†] Corn	Wheat	Cotton (Lint)[‡]
		Mg ha^{-1}	
Conventional	4.52	1.81	0.33
Conservation	4.65	1.90	0.38
$LSD_{0.05}$	NS	NS	NS

* Tillage for all three crops was significant at the 0.08 level by the F-test.
[†] Mean of four values (two-rotation replicates and two cycles through the rotation during 1988-1992).
[‡] Cotton yields are for three years due to an early frost in 1992. One bale of lint per acre is equivalent to 0.54 Mg ha^{-1}.
NS = not significantly different at the 0.05 level by the least significant difference test.

soil had received disking and mechanical cultivation for corn and soybean production during the previous 5 years.

Mean C values in the surface depths during years 1 to 3 ranged from 5.3 to 7.3 g kg^{-1} (0.53 to 0.73%), but there were no significant differences between tillage treatments within any depth. Crop residue removal treatments, which totaled about 15 Mg ha^{-1} (6.7 t/ac) during the first three years of the experiment, did not create significant differences in soil C content or crop yield (Karlen et al. 1984). Lack of statistical differences in C content during the first few years of conservation tillage is common and can be a problem in the short-term evaluation of conservation tillage systems (Langdale et al. 1990; Staley et al. 1988). The seventh year of the study produced the first statistically significant differences (Karlen et al.1989).

Differences in C content between the tillage treatments continued to increase after the seventh year. In years 9 to 14, the mean C content (mean values include both replicates of the rotation split) at the 0- to 5-cm depth in conservation tillage soil was nearly double the mean for conventional tillage: 12.0 vs. 7.2 g kg^{-1} (1.2 and 0.72%) (significantly different at $P \leq 0.05$). The C values for the 5- to 10-cm depth were also greater for conservation tillage ($P \leq 0.05$); values for conservation and conventional tillage were 6.3 and 5.6 g kg^{-1} (0.63 and 0.56%), respectively. The C differences between tillages in the 10- to 15-cm depth were numerically but not significantly different at the 0.05 probability level. The mean values of the 0- to 15-cm depth (Ap horizon) in years 9 to 14 were 5.7 and 7.7 g kg^{-1}(0.57 and 0.77%) for conventional and conservation tillage, respectively ($P \leq 0.05$). These differences in C content are sufficient to cause a change in the available soil water content according to Hudson (1994). He found a highly significant, positive correlation between soil organic matter content and available water content, particularly for sandy soils ($r^2 = 0.79$). An increase of organic matter from 0.5% to 3.0% (carbon content of 3 to 17 g kg^{-1}) (0.3 and 1.7%) more than doubled available water content.

The increase of soil C content over the 14 years in the surface 0- to 5-cm depth of the conservation tillage treatment is shown by a r^2 of 0.44 (Figure 1)(Table 2). The slope was 0.61 g kg^{-1} yr^{-1}(0.06%); and the probability that the slope was zero was < 0.01, indicating that it was very likely that the conservation tillage soil was accumulating C over time. The C content of the conventional tillage treatment had a very slight increase over the 14 years, but the slope of 0.13 g kg^{-1} yr^{-1} (0.013%) was four times less than for the conservation tillage treatment. There was also evidence of C content increase in the 5- to 10-cm depth of the conservation tillage treatment. The regression slope was 0.17 g kg^{-1} yr^{-1} (0.017%), which was 17 times greater than the 0.01 g kg^{-1} yr^{-1} (0.001%) slope of the conventional tillage treatment at that depth, and the difference in slopes was more than the standard error of the slopes. The probabilities that the slope was zero for the conservation and conventional tillage treatments were 0.04 and 0.80, respectively. This indicated that it was very likely that the conservation tillage soil was accumulating C, but it was very unlikely that the conventional tillage soil accumulated C. The lack of change in C contents in the 10- to 15-cm depth with either tillage was demonstrated by slope values that were < 0.06 g kg^{-1} yr^{-1} and by probabilities of zero slopes that were > 0.50 for both tillage treatments.

These data indicate that the crop residue additions were sufficient for increased C content of a sandy surface soil when surface tillage was absent, as was found by Blue (1979) on a Myakka (Aeric Haplaquods) fine sand in Florida pasture. Our data also show that row crop residue production was not sufficient to increase C under conventional tillage.

Soil C accumulation in a corn-wheat-cotton rotation. The tillage, rotation replicates, rotation cycles, and their interactions with tillage were not significantly different for soil C by the F-test ($P \leq 0.10$). However, the crop, depth, and depth by tillage interaction for soil C were significantly different at the ($P \leq 0.05$) by the F-test. The C content means (both rotation replicates for 2 cycles) in the upper 90 cm (35.4 in) of the soil after each portion of the corn-wheat-cotton rotations are presented in Table 3. The C content of the surface 0- to 5-cm (0- to 2-in) depth was significantly higher for conservation tillage than conventional tillage plots after each crop (Table 3). The 5- to 90-cm (2- to 35.4-in) depths with conservation tillage were generally numerically, but not significantly, higher in C ($P \leq 0.05$) than the conventional tillage soils when analyzed after each crop. The results of this rotation study suggest that introduction of cotton into the cropping sequence did not have a degrading effect on the C content of the soil in either tillage. In fact, actual soil C values after corn were slightly lower, most likely because crop residues were moderately high in all years. Corn residue was added in one year, and wheat residue supplemented cotton residue in the next.

Increased C, coupled with increased surface residue, can improve soil productivity by increasing capture and infiltration of water and reducing erosion (Langdale et al. 1992a; Langdale et al. 1992b). Individual crop yields were not significantly different for tillage treatments or for any crop in the corn-wheat-cotton rotation (Table 4). Nevertheless, crop yields for conservation tillage treatments were numerically higher for each crop, and conservation tillage was significantly ($P \leq 0.08$) higher for the mean yield of all crops in the rotation during 1988 to 1992. Thus, increased C and improved soil productivity were obtained during the production of normal row crop yields on a sandy southeastern Coastal Plain soil. Before modern conservation tillage technology was available, these increases in soil C were believed to be nearly impossible with row crop production, particularly if cotton and soybean were part of the rotation (Beale et al. 1955). Now, with modern conservation tillage technology, long-term conservation tillage of row crops appears to be a viable method of increasing the C content and consequently the quality of sandy southeastern Coastal Plain soils even when soybean and cotton are part of the rotation.

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